Exploring the Impact of Marine Debris on *Zostera marina* Ecosystem Productivity

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ABSTRACT

Seagrass meadows (i.e., *Zostera marina*), a vital component of coastal ecosystems, are facing degradation due to anthropogenic impacts such as marine debris and climate change. The relationship between marine debris and seagrass ecosystems is a subject of ongoing research, with the long-term effects of marine debris on seagrass productivity yet to be fully understood. This study aims to fill this gap by investigating the impact of marine debris removal on seagrass ecosystems, a crucial step in understanding and mitigating the effects of human activities on seagrass ecosystems. Two experiments were conducted in a seagrass ecosystem in Arikawa Bay, Nagasaki Prefecture, Japan, from April 2023 - July 2024. The first experiment evaluated the effect of removing marine debris (restored site) and allowing marine debris to persist (impacted site) on the coverage of seagrasses. The seagrass coverage was evaluated by assessing a total of 340 observation quadrats. Marine debris was collected and classified based on its material (plastic, metal, net/rope, glass/ceramic, cloth and rubber); total mass was recorded. The second experiment assessed the difference between the Net Ecosystem Productivity (NEP) of the impacted and restored seagrass beds using dissolved oxygen loggers. The first experiment revealed an increase in seagrass coverage of the restored area. The second experiment showed higher NEP (g C m^{-2} $month^{-1}$) in the restored site (mean±SD: 7.44±11.7) compared to the impacted site (mean±SD: 5.05±12). Our findings suggest that marine debris removal may positively contribute to seagrass ecosystem productivity. However, we are continuing to collect data to confirm these results.

Keyword: Dissolved oxygen/ Marine debris/ Net ecosystem productivity/ Seagrass/ *Zostera marina*

1. INTRODUCTION

Seagrasses are aquatic plants with organs and tissues similar to other flowering plants. Seagrass anatomy is separated into two parts, above and below ground. The above-ground part comprises shoots and leaves, and the below-ground part comprises roots and rhizomes/stems [1]. As a marine plant, seagrasses absorb carbon dioxide through photosynthesis [2], storing large amounts of organic carbon (OC) [3], and playing roles as a refuge and breeding ground for invertebrates and fishes [4].

Regardless of its benefits for the ecosystem, the presence of seagrass is suspected to be under threat due to the influence of marine debris. Marine debris is defined as all persistent manufactured or processed solid material disposed of or abandoned over coastal and marine environments [5], [6]. Currently, plastics have become the primary marine debris, accounting for about 80% of marine debris worldwide [7]. Therefore, plastic is widely considered a threat to marine ecosystems and wildlife [8], and many studies have documented the interaction between marine debris and nearly 700 species of marine wildlife [9], [10].

Our understanding of how marine debris pollution affects seagrass meadows is still evolving. Some studies suggest that seagrass can trap land-sourced debris [11]. Moreover, the trapped plastics could compete with seagrasses for space, reducing the availability of light and space, and thus affecting the growth of seagrasses [12]. Plastics alter seagrass architecture, prevent vertical rhizome growth, and increase seagrass vulnerability to invasion and sediment.

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While some studies are still ongoing, the potential for the long-term impact of marine debris in seagrass ecosystems remains unclear. We need further exploration of the effect of marine debris on seagrass meadows. This study explores the hypothesis that marine debris can affect the spatial extent and productivity of seagrass beds. We examine this hypothesis by removing marine debris and assessing how this influences seagrass growth and distribution.

2. METHODOLOGY

2.1 Location and sampling design

This study was conducted by skin diving every month from April 2023 to August 2024 in Arikawa Bay, Shin-Kamigoto, Nagasaki, Japan. The study site is in an area locally known as Yokoura (32° 59' 17.9376" N, 129° 7" 5.3112" E). The sea floor is mainly sand interspersed with rocky substrate. Only *Zostera marina* was observed at the site and was found at depths between 2 m and 7 m. In this study, we separated the site into two sections and conducted two experiments. In the first experiment, we removed marine debris every month on half of the site to identify the effect of marine debris removal on seagrass distribution and coverage over time. In the second experiment, various environmental loggers were deployed to analyze and estimate the net ecosystem productivity of the seagrass bed.

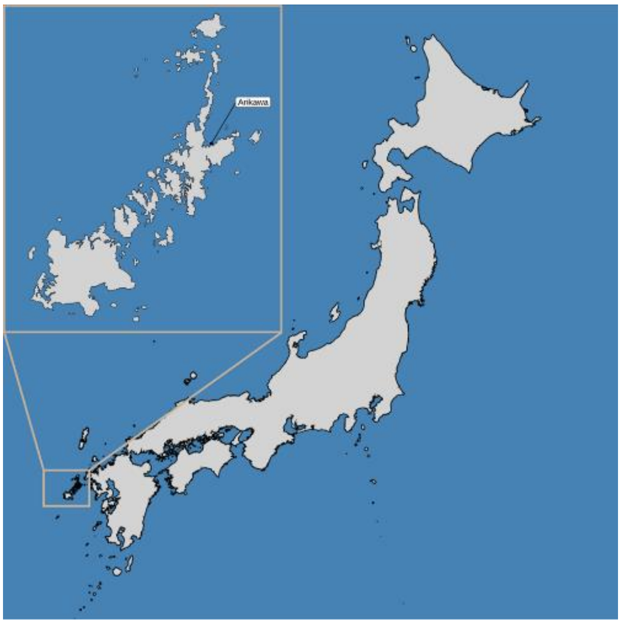

Figure 1. Study sites were located in Arikawa Bay, Shin-Kamigoto, Nagasaki, Japan.

2.2 Experiment 1

2.2.1 Marine debris removal

Marine debris was removed monthly. Initially, we separated the bay into two distinct sections. One section served as the impacted area, where marine debris accumulated naturally. The other section functioned as the restored area, which underwent monthly marine debris removal. Both designated sections of the site were characterized by pre-existing seagrass beds. Marine debris removal was done systematically, using a line transect so that seagrass coverage could be evaluated. A total of 10 lines were run across the site. Five transects for the restored section and five transects for the impacted section. Each line was approximately 70 m in length and spaced 5 m apart.

Macro-debris (size > 0.5 cm) was collected and classified based on material: plastic, net-rope, glass-ceramic, metal, cloth and rubber. After the collection, marine debris samples were washed with fresh water to remove sand, blotted dry, and weighed with a 0.1 g balance. Despite the six classified materials, we also grouped the marine debris materials into two groups: plastic-based material (plastic and net-rope) and non-plastic-based material (glass-ceramic, metal, cloth, and rubber).

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2.2.2 Seagrass cover analysis

The coverage of seagrass was done across each transect using a 50 × 50 cm photo-quadrat. At 2 m intervals, the quadrat was deployed, and an image was recorded with a digital camera (TG-6, Olympus). Images were analyzed to estimate coverage; a total of 310 quadrats were assessed every month. To analyze the coverage of seagrass, we adhered to the seagrass cover guidelines in the Guideline for the Assessment of Carbon Stock and Sequestration in Southeast Asia [13], which entails 11 standardized levels of percentage cover (5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100).

2.3 Experiment 2

2.3.1 NEP on seagrass beds

Net ecosystem productivity (NEP) on seagrass beds was done by monitoring various environmental variables during the study period. A total of 13 surveys were conducted from June 2023 - July 2024 for this study. A dissolved oxygen data logger (U26-001, Onset Computer Corporation, Bourne, MA, USA), wind speed sensor (S-WSB-M003, Onset Computer Corporation, MA, USA), and a datalogger (USB Microstation, Onset Computer Corporation, MA, USA) equipped with a PAR sensor (S-LIA-M003, Onset Computer Corporation, MA, USA) were used to record dissolved oxygen concentration, wind speed 1 m above the water surface and record Photosynthetic Active Radiation (PAR) light in the area of study.

The record sampling interval for all instruments was 10 minutes. The deployment positions of the instruments are in several locations. The dissolved oxygen data logger was placed 0 m and 1 m from the substrate of the seagrass Zostera marina beds in both impacted and restored areas. Meanwhile, the wind speed and surface PAR logger were placed 1 m above the water surface between the impacted and restored areas.

NEP was estimated using an open-water method, which integrates the environmental variables recorded using the data loggers [14].

2.4 Data analysis

To examine the seagrass coverage distribution and pattern, the spatial data representation was done using seagrass coverage and coordinates data on each seagrass point coverage analysis. All analyses were done with R version 4.4.1 (R Core Team 2024).

3. RESULTS AND DISCUSSION

3.1 Result

3.1.1 Marine debris

The amount of marine debris observed decreased over time as we removed marine debris (Fig. 2a). From the 16 surveys, a total of 31.1 kg of marine debris was collected. Nets were the most common debris materials. The net debris material is considered the highest marine debris by weight (40.9%) among the other materials, followed by ceramic (21.6%), metal (16.4%), plastic (9.35%), cloth (9.12%) and rubber (2.84%) (Fig. 2b). Interestingly, 90.73% of marine debris was found in the sandy area near the seagrass bed. In comparison, only 9.27% of marine debris was observed in the seagrass bed.

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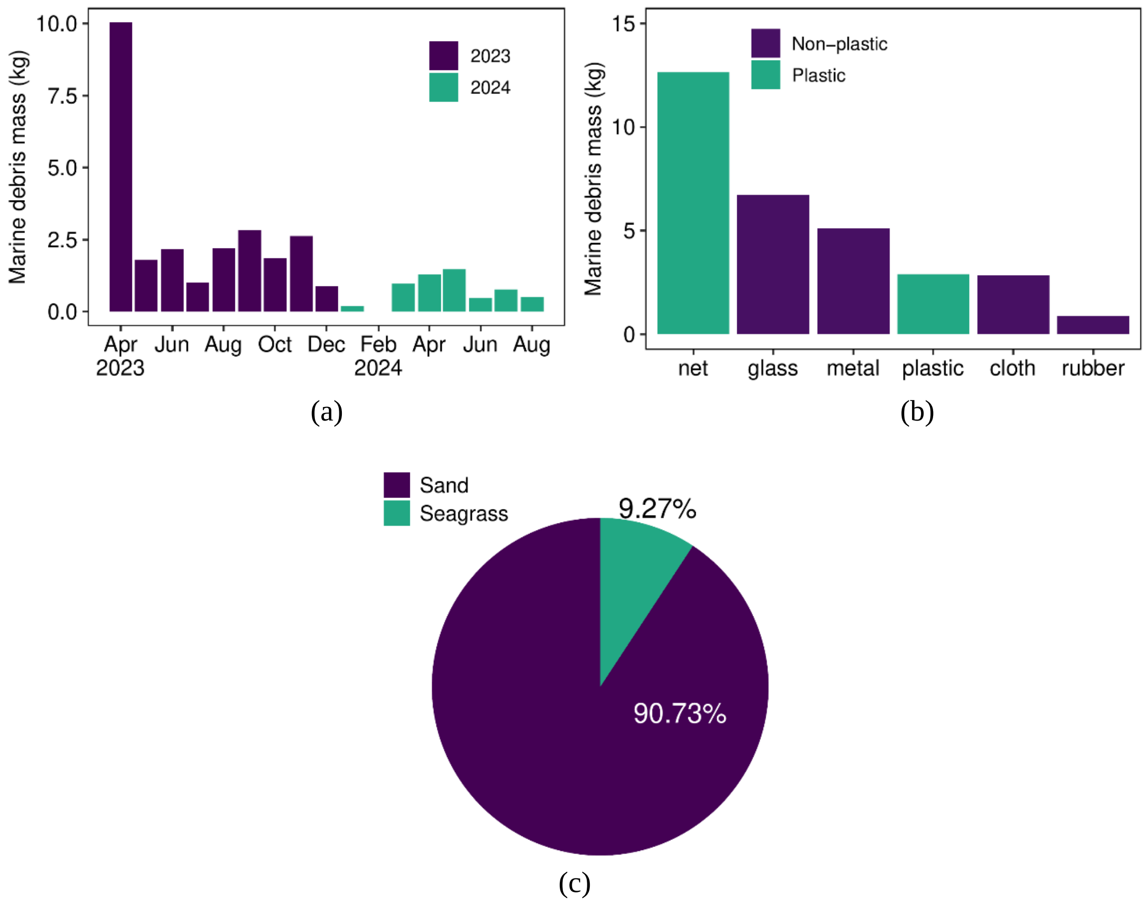

Figure 2. (a) Monthly marine debris mass, (b) Marine debris mass based on formed materials, (c) Marine debris percentage that was found based on location.

Based on our study, unvegetated areas, which are sand, store more marine debris than in the seagrass area. Moreover, marine debris observed in the sandy area was typically buried under the substrate, which allegedly could compete for space and affect seagrass distribution and growth [12]. Among the debris, the most common type was the net material, which was likely due to local fishermen repairing nets near the site. Note that the fishing nets that were being repaired were made up of polyamide (PA) fibres [15].

3.1.2 Seagrass cover

Seagrass coverage in 2023 was highest in July at both the impacted area (58.5%) and the restored area (50.3%). While in 2024, the highest seagrass coverage was in June for the impacted area (59.8%) and in July for the restored area (51.8%) (Figure 3a). Moreover, after one year of study between 2023 - 2024, the seagrass cover increment between impacted and restored areas were 6.03% and 20.1% respectively (Figure 3b). A Welch's t-test was done to examine how the seagrass coverage changed after one year. In the impacted area, the test revealed a t(7.5)=-0.87, (P=0.4132), whereas in the restored area, t(5.9)=-3.28 (P=0.0173).

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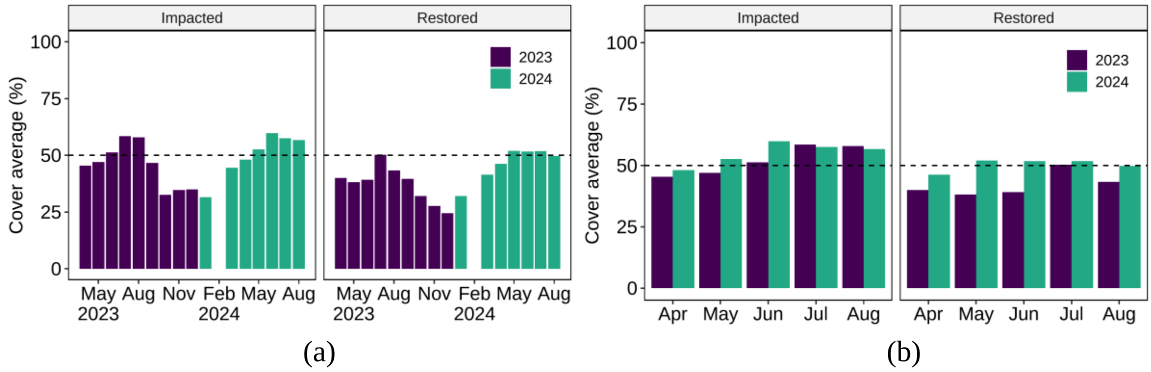

Figure 3. (a) Monthly average of seagrass cover, (b) Seagrass cover increment from both areas after one year of study.

Our study shows that the effect of marine debris removal on the seagrass bed positively contributes to increased seagrass coverage and distribution. After one year of study (Fig. 3b), the average increase in seagrass coverage was 6 % in the impacted area. However, the average increase in seagrass coverage was 20 % in the restored area. It is relevant to note that the coverage of seagrass in the impacted area was initially higher than that of the restored area, which strongly suggests that marine debris removal greatly enhanced the increase in coverage of the restored area.

3.1.3 Seagrass Net Ecosystem Productivity (NEP)

The average net ecosystem productivity throughout the study was (mean±standard deviation) 5.05±12 g C m^{-2} day^{-1} for the impacted area and 6.83±11.1 g C m^{-2} day^{-1} for the restored area (Figure 4). The average monthly NEP was lowest during July and peaked during January to March. However, for the impacted area, NEP was negative (i.e., the ecosystem was heterotrophic) during both years of July. In contrast, in the restored area, NEP was only heterotrophic during the beginning of the study. It appears that after one year of removing marine debris, the restored area achieved an autotrophic state, given that the impacted area reverts to a heterotrophic state after one season.

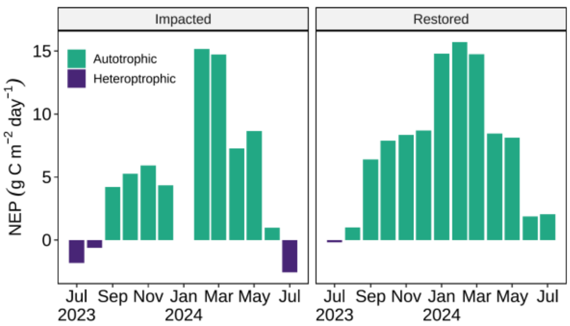

Figure 4. Monthly seagrass net ecosystem productivity estimation.

Based on our study, we suggest that the long-term effect of marine debris on seagrass beds is decrease in productivity. For example, fragments of plastic (e.g., high-density polyethene) buried in marine sediments negatively impact the growth and structure of the seagrass *Cymodocea nodosa* [16], which may have occurred at our site. Plastics accumulating in sandy sediments may inhibit the gas exchange between sediments and the overlying seawater, affecting oxygen exchange [12]. This suggests that not only oxygen but also the flux of other nutrients may be affected by accumulating marine debris, which will likely influence productivity. Recall that seagrass roots require oxygen for respiration, which is important for energy production. Consequently, interfering with oxygen exchange can lead to hypoxic conditions that can reduce the growth and biomass production of seagrasses [17]. Additionally, we

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suggest that marine debris in seagrass beds can physically interfere with root expansion and seed germination.

4. CONCLUSIONS

Marine debris in seagrass beds affects growth and productivity, likely due to physical stress. Our study suggests that removing marine debris has positive impacts since we observed increased seagrass coverage and productivity. However, the mechanisms regarding how marine debris affects coverage and productivity remain unclear. More studies are needed to reveal how marine debris affects seagrass meadows, not only the seagrass species but also the organisms associated with this ecosystem.

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